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THE USE OF W. BUDRYK - S. KNOTHE THEORY FOR FORECASTING OF MINING EXTRACTION INFLUENCES ON THE UNDERGROUND STRUCTURES

POUŽITÍ BUDRYK-KNOTHEHO TEORIE PRO PŘEDPOVĚĎ VLIVŮ HLUBINNÉ TĚŽBY NA PODZEMNÍ OBJEKTY

Abstract

The application of geometric-integral theories for forecasting of rock mass deformation due to underground mining on the example of wide-spread used in Poland W. Budryk - S. Knothe theory has been discussed in this paper. Specialized own tools for calculations in the 3D mesh have been presented, as well as possibility of employing commercially available software for graphical processing of the calculation results. Presented system can be used for forecasting of deformations in the vicinity of underground structures.

Key words :mining subsidence, geometric-integral theories, rock mass deformations

Abstrakt

V tomto příspěvku je diskutována aplikace geometrické integrální teorie pro předpověď deformací v masívu následkem hlubinné těžby s využitím Budryk-Knotheho teorie, která je v Polsku široce rozšířená. Je představen nejen vlastní software pro 3D výpočty, ale také komerčně dostupný SW pro grafické zpracování. SW je možno použít pro předpovědi deformací v okolí podzemních objektů.

1 INTRODUCTION

Forecasting of underground mining influences on the rock mass has been under researchers' effort for several decades. Development of theoretical models for analyses of deformation state in the vicinity of underground structures is difficult mainly due to lack of surveys led in the underground workings, so it is hard to do the verification of these models. For many years W. Budryk – S. Knothe (B-K) theory has been used in Poland for forecasting of land surface deformation due to underground mining [4, 6]. There were some modifications made later, that enable using it for determination of deformation indices inside the rock mass. This modification consists in alteration of main influence range r definition. This alteration leads to dependence of r on the vertical location of calculation horizon z above extracted seam – fig.1:

$$r_z = r(z) \tag{1}$$

where:

r – the radius of main influence range for land surface

rz – the radius of main influence range inside the rock mass at the horizon z above extracted seam

So it is assumed that rz varies inside rock mass from the roof of extracted seam up to the land surface.

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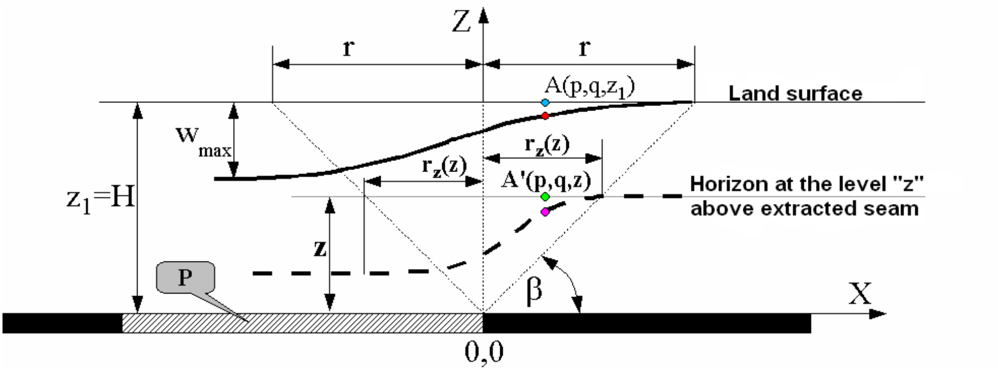


Fig.1: The sketch illustrating calculations of mining subsidence inside the rock mass

Taking into account this assumption enables us to calculate subsidence of point A' located inside the rock mass at the horizon z, due to extraction of seam area P, by using following formula [5,6]:

$$w(x,y,p,q,z) = \frac{w_{max}}{r_z^2} \iint_{P(x,y)} e^{-\pi\frac{(x-p)^2+(y-q)^2}{r_z^2}} dxdy \tag{2}$$

The rest of deformation indices are calculated in the same way as for the land surface, by derivation of equation (2) and using of Aviershin relation for determination of horizontal displacement and strain.

The last question to answer is how to describe the variability of rz from the roof of extracted seam up to the surface. There are several propositions worked out in this field. The basic one is formula (3) proposed by S. Knothe, other were worked out by B. Drzęźla, M. Chudek, J. Zych and others [1, 2, 6].

$$r_z = r\left(\frac{z}{H}\right)^n \tag{3}$$

where:

r	–	main influence radius for land surface,
H	–	the depth of extraction calculated from the surface,
n	–	coefficient. Some considerations on its value one can find in [3].

Second branch of models describing intrinsic rock mass deformation under influence of underground mining are the numerical methods. There are several models one can find here: the finite element methods (FEM) with an assumption of rock mass continuity, boundary element method (BEM), finite difference (FDM) and distinct element methods with an assumption of discontinuity of rock mass. There are lots of commercially available software solutions that aid engineers in recognition of deformation state in the vicinity of underground constructions.

The main advantage of these solutions is the possibility of using different constitutive models for describing rock mass behavior with using real or close-to-real geometry and mechanical properties of layered rock mass, as well as their changes over time due to extraction field advance and goaf convergence.

The results of such calculations can be precisely analyzed by using of graphic postprocessors bundled with the software. For example, one can present the distribution of deformation indices along arbitrary cutting planes through the rock mass.

One should keep in mind however, that important limitation in using these methods for forecasting tasks is the lack of reliable data describing properties of individual rock mass layers, as well as their variability due to extraction influence. So quality of prognoses made with using these tools are weighted by mentioned factors and it is really hard to estimate the rate of errors that could arise.

Mentioned above problems with practical forecasting tasks by using of numerical methods causes that geometric-integral models (especially B-K theory in Poland) still enjoy great popularity. They characterizes the accuracy sufficient for practice and, as another advantage, the range of data necessary for calculations is narrow and easy to obtain. On the other hand, software systems that utilize these models are not usually well equipped with graphical postprocessors for the 3D rock mass deformation presentation. In recent years there have been issued commercially available graphical systems for 3D data processing at relatively low cost - one of them there is the VOXLER program [7].

Below, there have been presented possibilities of using B-K theory for prognostic calculations of 3D rock mass deformation with utilization of author's own software named DEFK and post-processing of their results with the VOXLER program.

2 SHORT DESCRIPTION OF THE SOFTWARE

The DEFK program [5] enables forecasting calculations of deformation indices by using B-K theory for final and transient state. Calculation points can be located on the surface and inside the rock mass in certain system of points as follows:

- for regular 2D grid,
- for points located along straight line,
- for system of scattered points,
- for regular 3D grid.

Following the most important calculation procedures are available:

- calculation of final or transient state of deformation for specified extraction time period,
- searching of maximum deformations with taking into account development of extraction front,
- calculation of the distribution of deformation indices over time with taking into account development of extraction front,
- determination of B-K theory parameters: {a, tg□, d, c}

Apart from functions mentioned above, the program is equipped with several auxilliary functions, among other things for preparing grid files (*.GRD) and boundary files (*.BLN) used in mapping.

The VOXLER program is designated for 3D data visualization purposes. It can join 3D data from different sources into one presentation that consists of scattered points map, isoline, isosurface and vector maps. It is equipped with powerful gridding algorithms taken from Golden Software Surfer system. Worked out visualizations one can rotate, change point of view, use arbitrary oriented cutting planes for better interpretation of calculation of measurements results.

3 THE EXAMPLE OF DEFORMATION STATE FORECASTING IN THE AREA OF SAFETY PILLAR FOR SHAFT

The exploitation of three longwalls at the depth of 500 m inside the mine shaft safety pillar has been taken into consideration. The land surface near the shaft is located at +225 m above sea level (a.s.l.). At the horizon +50 m a.s.l. the system of main development headings is located according to fig. 2. Extraction is planned to be led from the western part of the safety pillar toward east.

By using DEFK program, exemplary deformation state inside rock mass was calculated, taking into account extraction state as presented in fig. 2 with thick line.

Calculations were done for cuboid solid of rock mass as presented in fig. 3. The volume of considered solid of rock mass was covered by 3D mesh of calculation points. For each calculation point the subsidence (w), maximum horizontal strain (□max) and vertical strain (□z) were calculated. Totally more than 67.000 points were calculated (DEFK program enables calculation inside rock mass for maximum 1 mln points). For approximation of main influence range rz variability inside the rock mass, formula (1) was used with n=1.0 (linear variability of rz(z)).

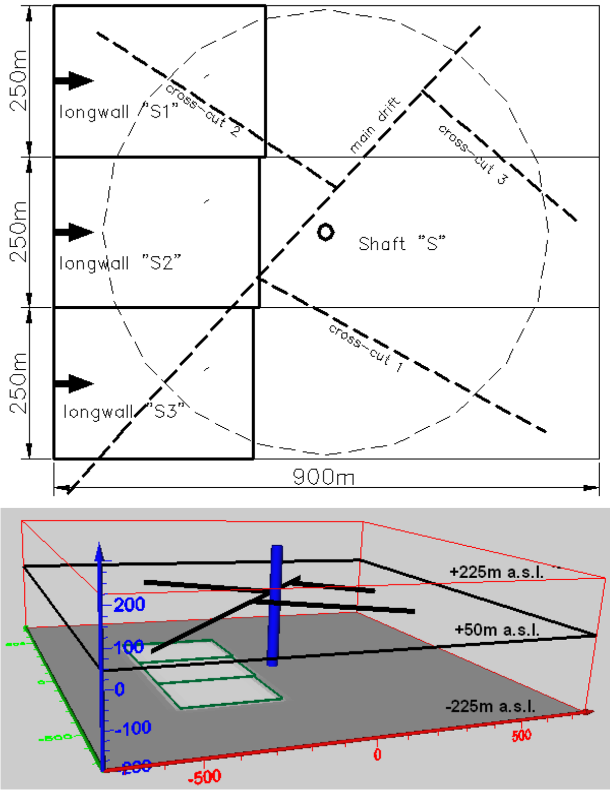


Fig.2: Location of planned extraction in relation to the shaft and development headings

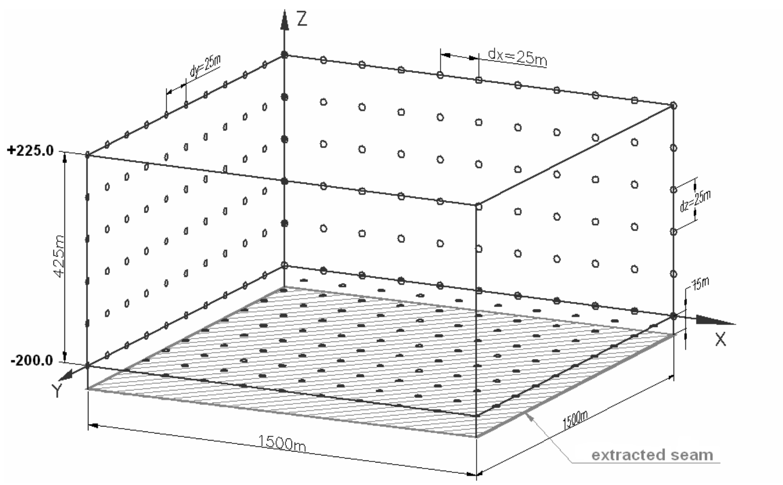
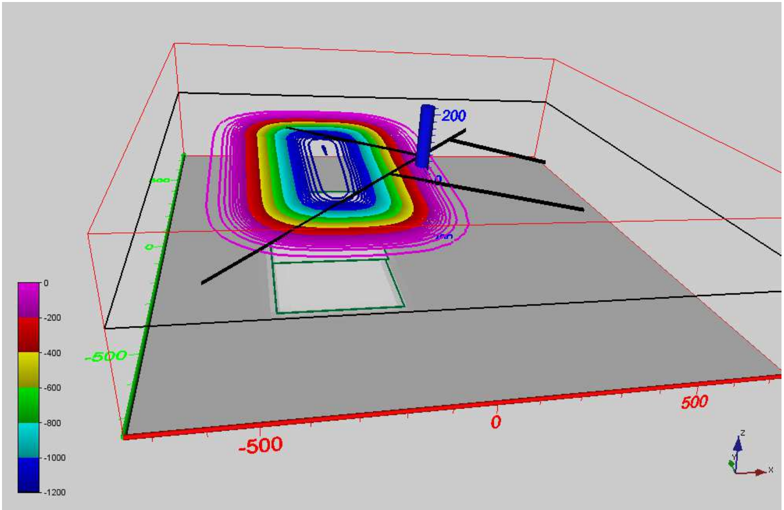


Fig.3: The sketch of calculation solid of rock mass



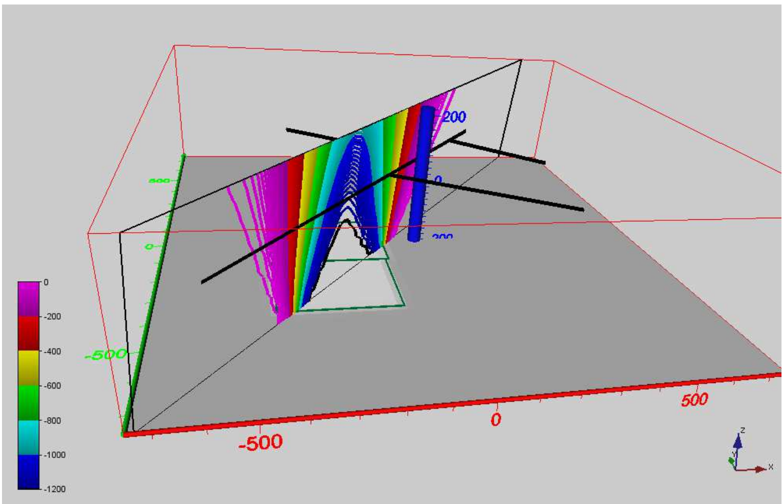


Fig.4: The distribution of subsidence w for considered exploitation state

a) on the horizontal plane +50 m b) on the vertical plane along main drift

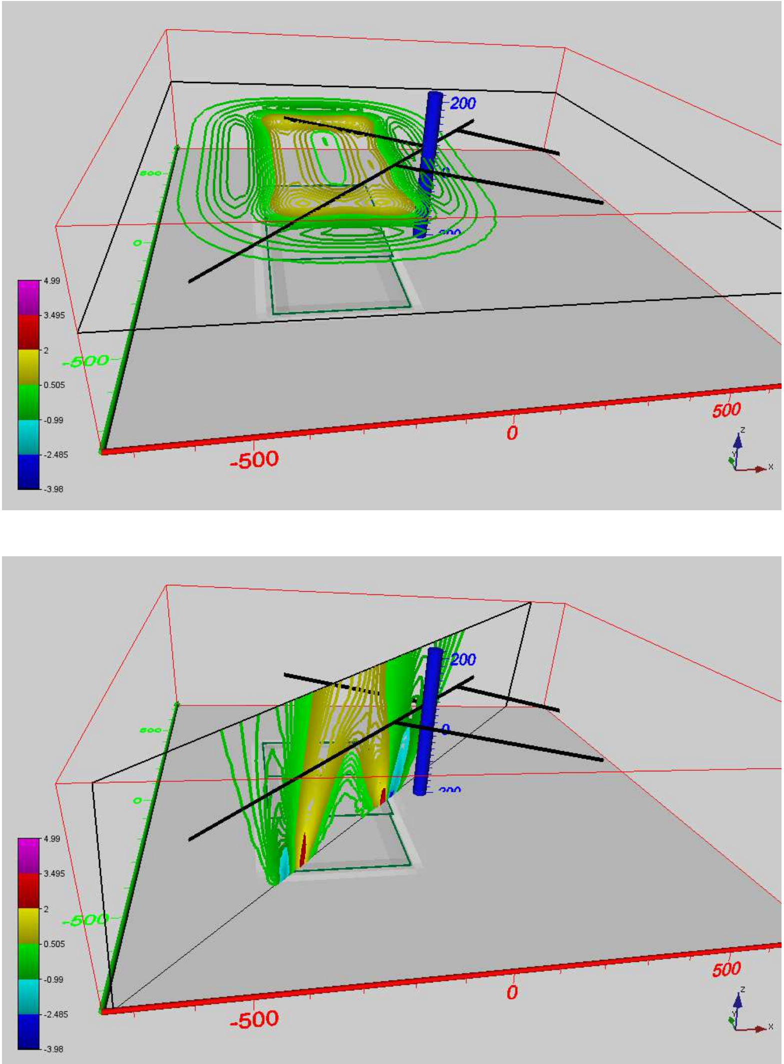


Fig.5: The distribution of vertical strain ε_z for considered exploitation state

a) on the horizontal plane +50 m b) on the vertical plane along main drift

For graphical processing of the calculations results, they were imported into the VOXLER. Imported grid was interpolated from density of 25 m used in calculations to 10 m for smoothing purposes (usually one can use the same grid density). In fig. 4-6 some characteristic distributions of w, ε_{max} and ε_z were presented as contour line maps along specific cutting planes: horizontal plane at the level of development headings +50 m a.s.l. and vertical plane (cross section) with the orientation along main drift.

Additionally, in fig. 7 the possibility of isosurfaces map has been presented. In this exemplary map, the distribution of horizontal strain is presented for isovalues of: ε_{max}=+3‰ and ε_{max}=-3.0‰.

3 CONCLUSIONS

Summing up presented material, one can state that current software tools enable quick and comfortable working out of the multi-variant prognoses by using W. Budryk-S. Knothe theory together with advanced graphical interpretation of the results. Used for several years tools for generation of the 2D maps of deformation distribution now we can extend towards 3D presentations of intrinsic rock mass deformation state. One of the alternatives in this field there is the system presented in this paper.

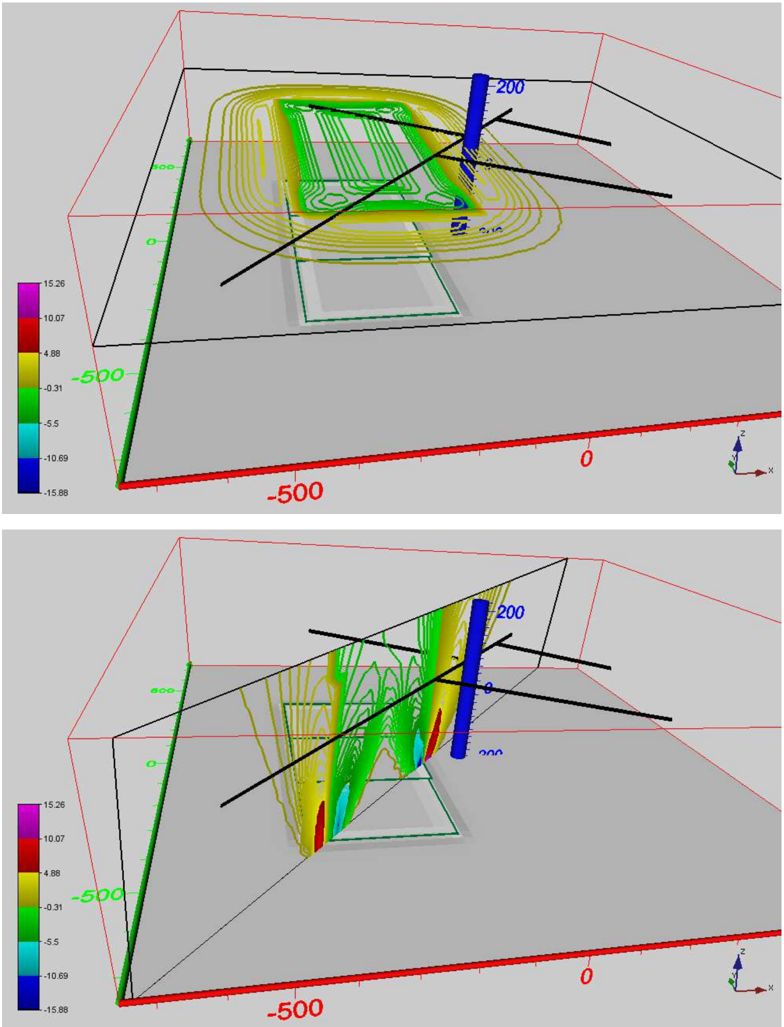


Fig.6: The distribution of horizontal strain □max for considered exploitation state

a) on the horizontal plane +50 m b) on the vertical plane along main drift

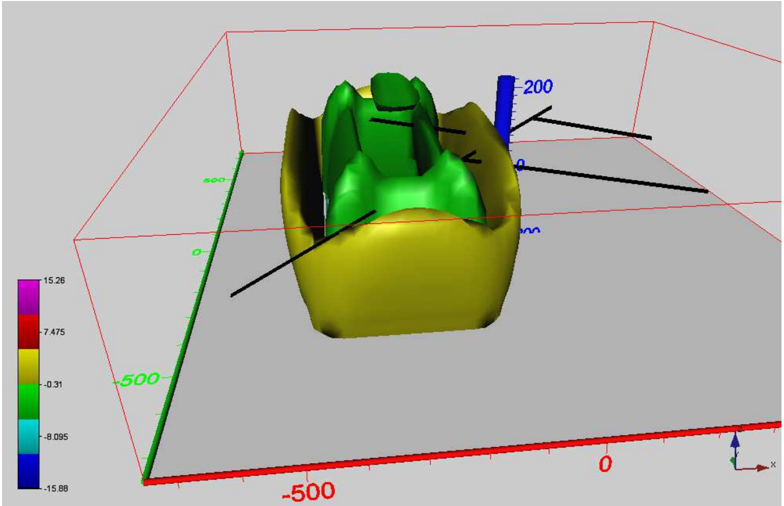


Fig.7: Isosurfaces of horizontal strain □max=±3.0‰

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